

A Call for a Transport Initiative

US Transport Task Force

Presented by P.W. Terry

TTF: Examination of need for new resources in transport science

TTF response to transport diagnostic initiative long advocated by R. Stambaugh

Year long discussion in TTF (forums in meetings, presentations at labs)

Within TTF, broad consensus:

Remarkable progress to date, but mostly on ion thermal transport

Crucial problems remain to be solved

Present capabilities/facilities not configured for solving remaining problems

Need new investment in diagnostics, exp/theory manpower and tools, while continuing existing efforts

Community ready to develop tools, tackle problems

Transport Initiative

- OFES sponsored
- *Increment* to existing funding within fusion program
 - Focus in target areas, while not diverting efforts from existing transport projects, goals
 - Unfunded mandate would negatively impact progress in transport science
- For transport studies encompassing expt, theory, modeling
(redressing existing imbalances)
- ~ \$20 M/year for 5 years
- Funding to worthy projects on basis of proposal competition

Arguments follow

Transport is crucial problem in fusion energy science

Example: ITPA Coordinating Committee: 6 of 11 actions requiring greatest emphasis in worldwide fusion physics experimental program (2002) are directly related to transport

For success in fusion:

- Characterize local fluctuations and transport
- Understand basic mechanisms responsible for transport
- Control transport processes

Must be applied to:

- Ion thermal transport
- Electron thermal transport
- Particle transport
- Momentum transport
- H mode and pedestal physics

Significant advances made as result of heightened effort

1988: DOE reprogramming placed transport as top priority for magnetic fusion program

□ ~ \$25M for new & existing diagnostics, analytic theory, computation

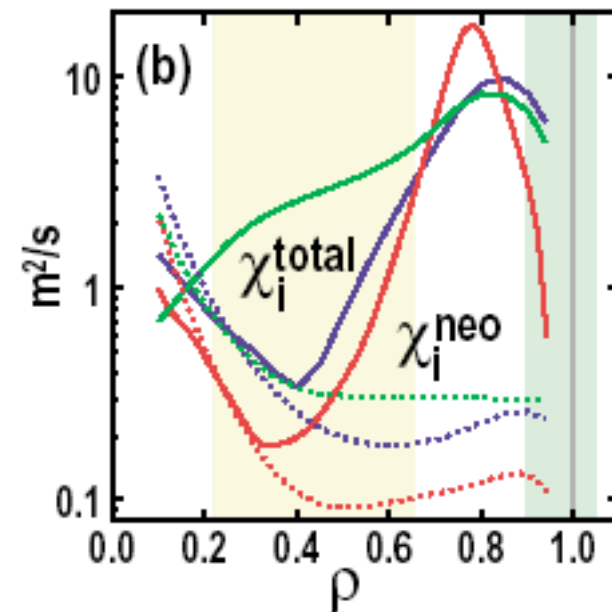
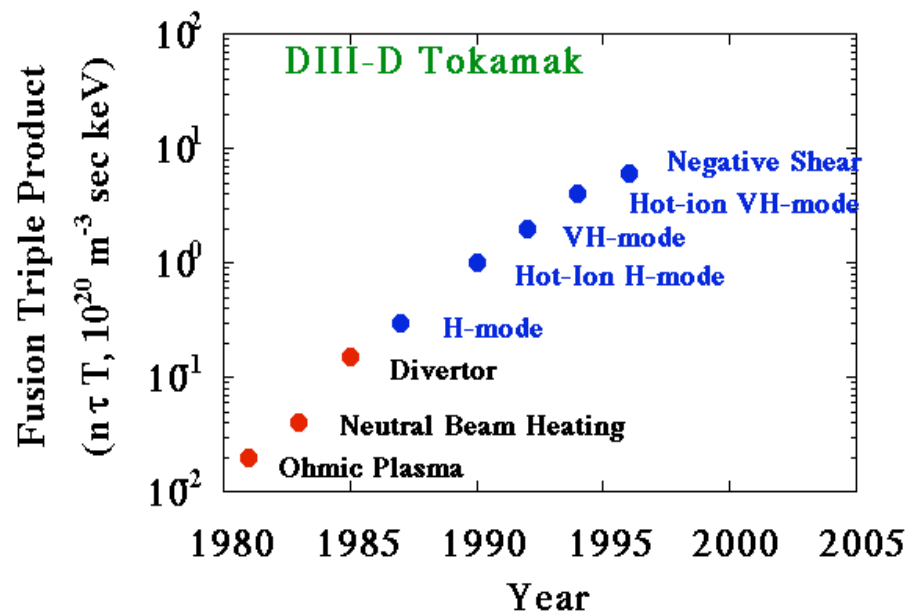
Since 1988 significant advances have been made

Most notably:

- Ion thermal transport routinely controlled
 - Lowered to level of neoclassical transport
- Fluctuations responsible for ion thermal transport identified
- Advances in modeling fluctuations, turbulence, transport

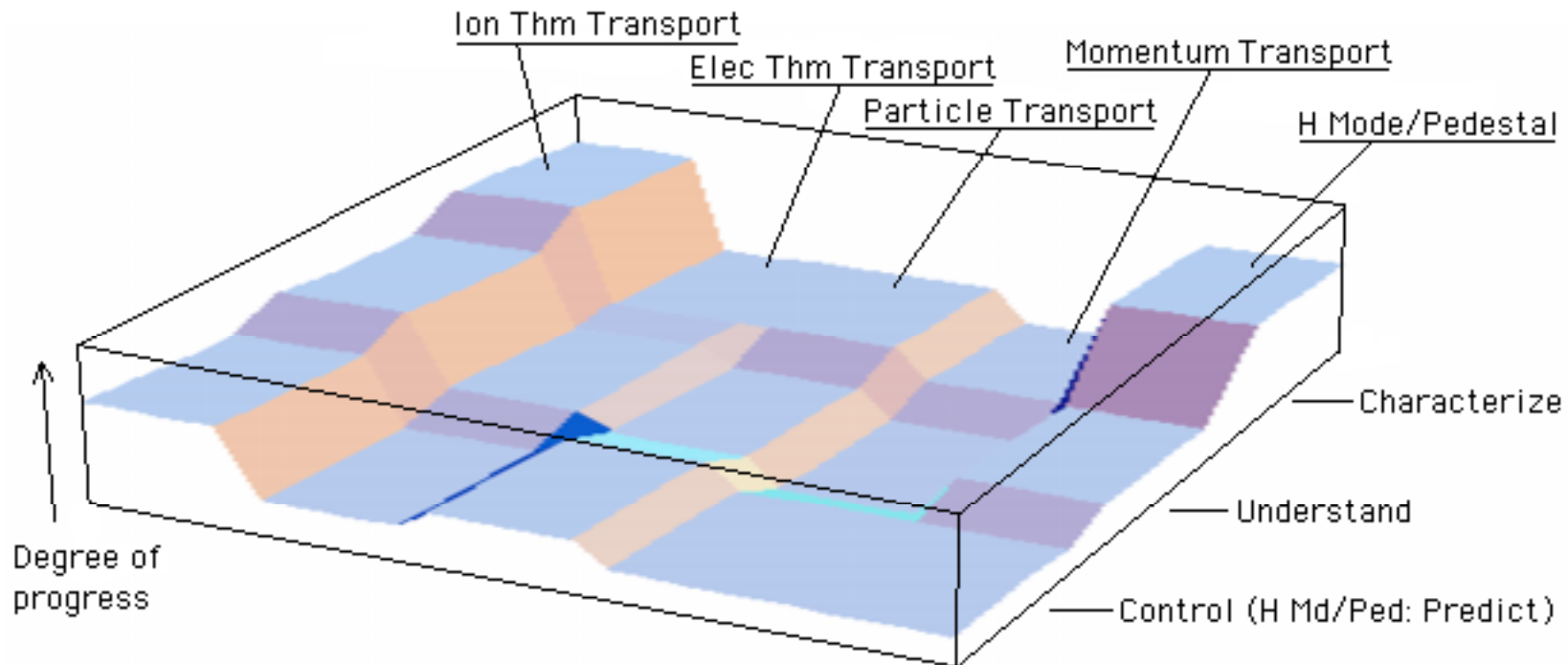
Highlights: Progress in ion thermal transport

- H mode
- Flow shear suppression paradigm
- VH mode, Internal transport barriers
- Internal barriers with edge control (QDB, EDA)



- Control of ubiquitous, highly self-organized dynamical state (ion scale turbulence)
- Based on understanding of basic processes
- NRC: χ_i progress allows fusion to proceed to burning plasma experiment

Significant problems remain to be solved



Remaining problems crucial for control (ash removal, impurities, pedestal, flow shear)

Remaining problems crucial for success in reactor environment

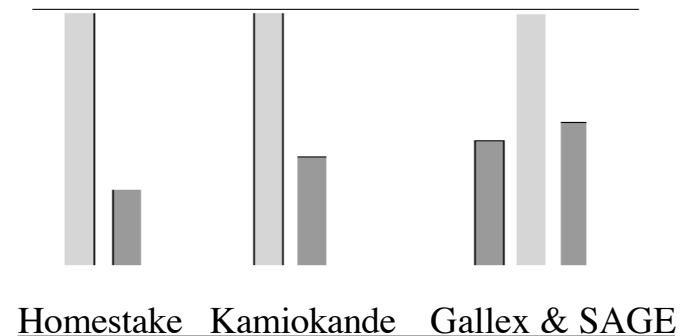
Uneven progress □

- Existing diagnostics provide window on ion scale fluctuations
- Ion scale fluctuations susceptible to fluctuation-independent suppression mechanism
- Existing diagnostics/theory/modeling not adequate for remaining problems

Example: solar neutrino problem

- Solar neutrino model predicted neutrino flux
- Detectors observed $\sim 1/2$ predicted flux
- Modest deficiency \square big resource commitment
 - Solar model refinements
 - New theory \square neutrino oscillations, mass
 - Importantly: Major new detectors

Neutrino Shortfall



- Results: windfall of advances - solar model confirmed, neutrino mass confirmed, oscillations confirmed; implications in many areas
- Model refinements and new theory were not deemed to be solution to problem until observations confirmed and validated ideas

If 50% shortfall is worthy of such response, so should

- Absence of \square_e reduction when ion transport is quenched in ITB
- Absence of electron fluctuation signal in presence of large electron heat flux
- Absence of predictive capability for H-mode transition, pedestal

Now is the time to mount next initiative in understanding transport

- Existing (ion scale) diagnostics are yielding diminishing returns in new discoveries

New windows □ new discoveries

- Computation has reached new level of sophistication
 - Codes now incorporate much of relevant physics
 - We think we have all the basic ideas in hand
 - On certain topics, experimenters cannot engage in lively discussions among modelers and theorists (electron scale fluctuations)

Experiment and diagnostics must keep pace for bona fide progress

- New ideas for diagnostic development and analysis at maturation
- Answers for key fusion questions needed now

Transport initiative is compatible with other initiatives

Transport initiative compelling in its own right - should go forward irrespective of how other initiatives fare

Burning plasma initiative

- Transport initiative: ideal base program activity in US program with ITER
 - Impact ITER performance, experimental program
 - Key contributor to US role in ITER
 - Impact conception, design of next step
 - Advances basic science *and* progress toward fusion
 - Makes use of OFES portfolio of devices

Computing initiative

- Gains in computer power, simulation capability outstripping ability of experiment to validate models
- Successful computing initiative requires commensurate effort to improve diagnostic capability

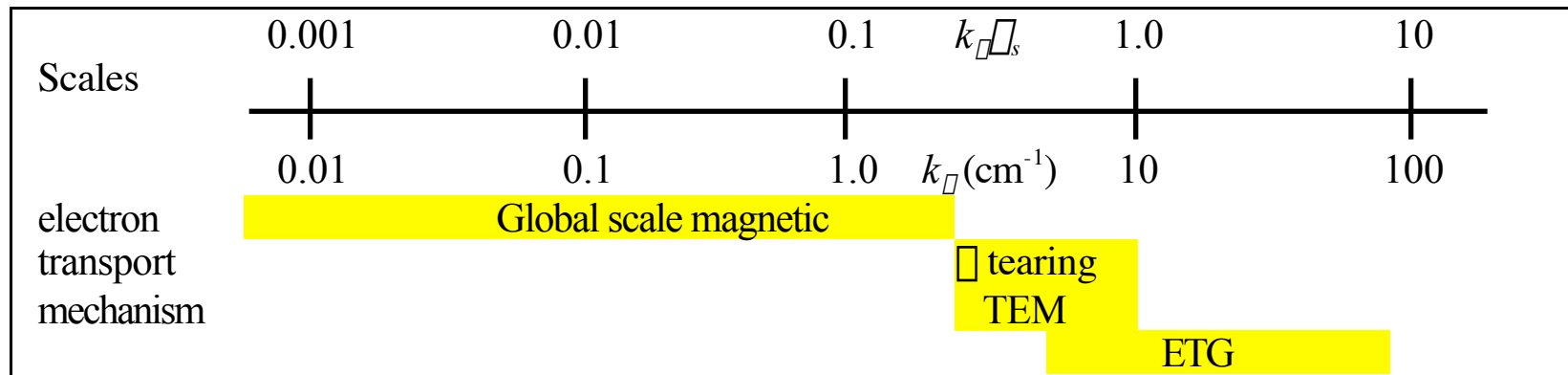
Electron thermal transport compelling as a focus for initiative

- Understanding and control of χ_e crucial

- For $T_e \geq T_i$, high density, electron channel limits global confinement
- Likely impacts profiles

- Many outstanding problems in electron thermal transport

- Cause of χ_e anomaly not known
- χ_e not reduced in ITBs with χ_i reduction - physics not understood
- No χ_e candidate has been ruled out (incl., global \tilde{b} , TEM, χ -tearing, ETG)



- Not known whether χ_e driven by magnetic or electrostatic fluctuations
- Possibilities span available scales, available modes

Solving electron problem will likely require new diagnostics, resources

- High k fluctuation diagnostics (FIR, interferometry, phase contrast imaging)

Ideally: measure $\beta_i < k^{-1} < \beta_e$

resolve k_r, k_\parallel

correlation lengths

bispectra, bicoherence

- Core magnetic fluctuation diagnostic
- Profile diagnostics on smaller devices

Device scan (Spheromak \square RFP \square ST \square tokamak \square stellarator)

Study characteristics of β_e

Scan discharges ranging over \tilde{b}^2/ϵ^2

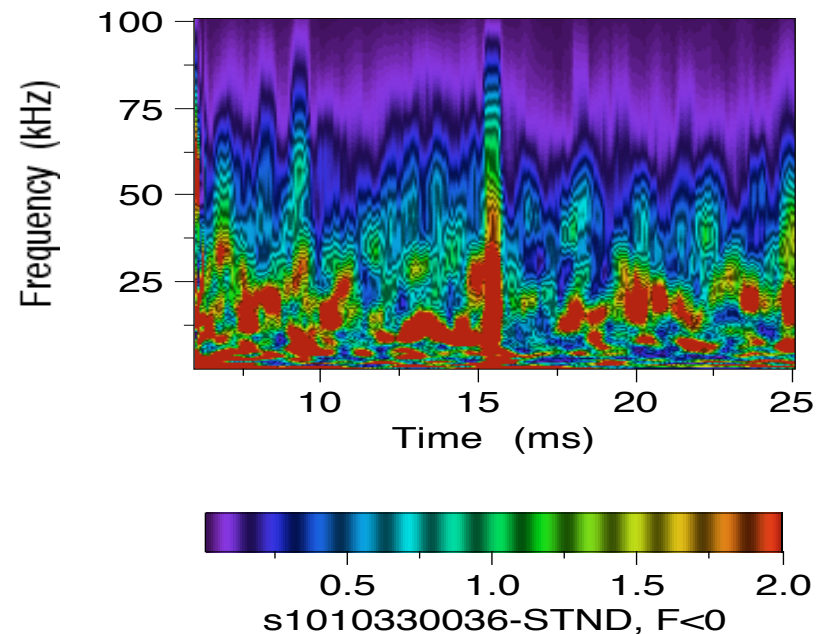
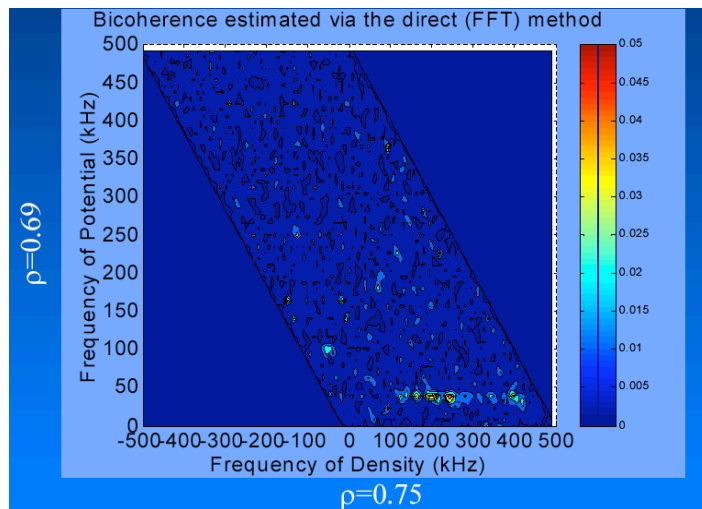
Scan \square

- Methods for testing β_e theories without \tilde{b} diagnostics

Transport community is prepared to attack electron problem

- Promising techniques available or under development

- Electron barriers created with auxiliary electron heating (β_i not always reduced)
- FIR polarimetry (Faraday rotation)
- Fluctuation bispectrum, bicoherence
Probe structures, cascades, nonlinear instability (secondary, tertiary)
- Extensions of fluctuation diagnostics to β_e scales
- Computation



H mode/pedestal physics compelling as focus for initiative

- H mode essential for all tokamaks, burning plasma experiments
 - High β , high Q , high β , high temperatures, control edge environment
- Many outstanding problems in H mode and pedestal physics
 - Edge turbulence process not understood
 - No predictive capability for H mode transition
 - Not known what determines pedestal width, height
 - Correct scalings for transition, pedestal width, height not known
 - No generally valid model for H mode transition, barrier evolution
 - Not known what sets pressure limit in ELM regimes
- Solving H mode/pedestal problem will likely require new resources
 - Significant increase in number of scientists working in this area needed
 - Extension of transition models to obtain testable predictions
 - Development of more complete, self-consistent, integrated pedestal models needed (incl. energy flux, particle flux, profiles, realistic geometry, fueling)
 - Edge current diagnostic needed
 - Profile diagnostics with better spatial, temporal resolution
 - Analysis advances for application to visualizations

What deliverables list might include

In 5 year period, significant probability that

\square_e

Implement electron scale fluctuation diagnostic

Determine whether electron scale fluctuations responsible for \square_e anomaly in ITB

Determine fraction of \square_e attributable to magnetic, electrostatic fluctuations

Determine type of fluctuation responsible for \square_e anomaly

Make significant progress on control of electron thermal transport

H/Ped

Create and refine integrated model

with MHD, dynamically realistic fluxes, boundary physics, atomic physics

Perform detailed experimental tests

Make significant progress toward predictive capability

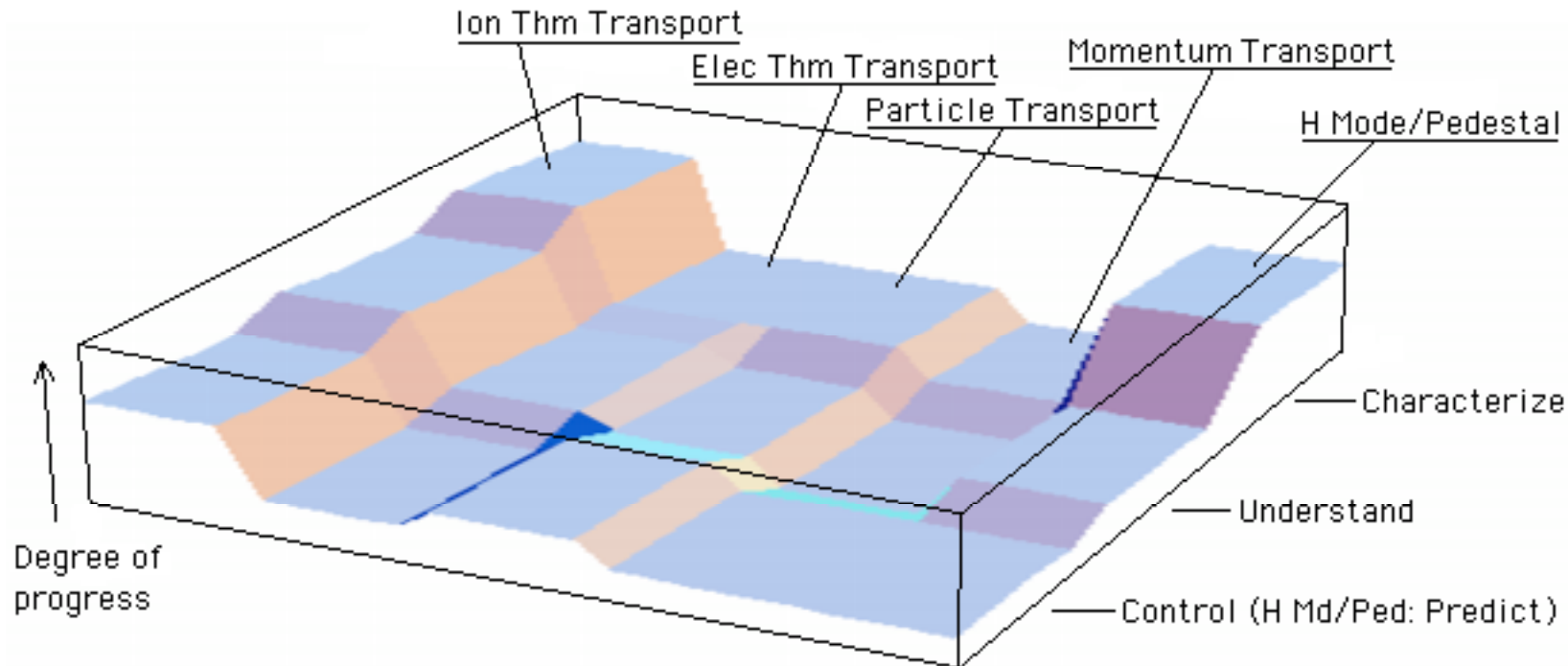
Pedestal height, width, scalings

Threshold scalings

Cross fertilization \square Significant progress in other, non targeted areas

The Transport Task Force advocates a national transport initiative

Significant transport progress to date limited mainly to ion thermal conduction



Existing diagnostics, capabilities not suited for solving remaining problems

- Identify focus area, attack with funding increment
- Focus not to drain efforts from existing transport studies
- For new diagnostics, better use of existing diagnostics, theory, modeling
- Community developing tools to tackle problems